STOCK AND (POSSIBLY) PATH DEPENDENT TECHNOLOGIES

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ABSTRACT

According to conventional economic wisdom the economically more efficient technology will always outcompete the less efficient. This hypothesis has usually been taken to hold for the exploitation of common pool renewable natural resources such as fish stocks. This paper claims that, while this is not necessarily false, it may be too optimistic. The paper shows that what constitutes the most efficient technology may switch depending on biomass size. It also shows that once effective fisheries management is introduced and biomass recovers, a return to the initially most efficient technology may not be possible because of its embeddedness in traditional knowledge and institutions which might have become forgotten or lost. Thus, there may be a degree of technological irreversibilty in fisheries and other natural reource utilization. The paper's findings seem relevant to many situations in developing countries fisheries where labour-intensive technologies are displaced by more capital-intensive technologies, often introduced with government subsidies. The uncontrolled expansion of the latter then creates the condition, i.e. reduced stock sizes, especially in inshore areas, that disadvantages the intially more efficient labour-intensive technologies.

Keywords: Fisheries technology, technological switch in fisheries, inefficient technology use

INTRODUCTION

Economic theorists like to talk about production sets and technologies (Solow 1956, Malinvaud 1972 and Romer 1996). Appealing to profit maximizing behaviour and market forces, it is typically assumed that producers select the most efficient technology from the set of available ones (Hicks 1946, Debreu 1959, Arrow and Hahn 1971). This naturally leads to the possibility of technological switches, i.e. the replacement of one technology for another, as the output level alters (Samuelson 1951, Burmeister 1980).

In reality, however, there is no big reference book containing technological blueprints. Technological knowledge is maintained (and lost) in much more complex ways. Notwithstanding a great deal of written material found in libraries, on the internet and institutes of technological knowledge, much technological knowledge is held in human brains and passed along by various kinds of social intercourse. This implies that certain technologies may be forgotten and lost to humanity. Moreover, in any given social group some technologies may not be accessible even if they are known to the human race as a whole.

It follows that the set of technologies from which real producers select is often quite incomplete. The best technology for the job may have been forgotten or it may be unknown to the social group in question. In both cases we may talk about a shrunk technology set. In the first case, the only market forces which can remedy the situation are those that encourage invention in general. Market forces, on the other hand, will eliminate the second case relatively quickly if the profitability of increased technological knowledge is high enough.

This paper explores some possible implications of the first case in fisheries. More precisely, it considers the situation where the profit maximizing technology depends on the size of the fish stocks which are variable over time. This implies technological shifts in the fishery as the size of fish stocks passes certain trigger points. Indeed, it commonly observed in the world's fisheries that declining fish stocks are accompanied by a shift to more intensive harvesting technologies. However, even when fish stocks substantially recover (which actually happens (Arnason et al. 2000), it is rare to see a movement back to the old harvesting technologies. This may be because the old technologies are not efficient, even at large stock sizes. But it is also possible that they would be efficient but have simply been lost from the set of available technologies set. They may have become forgotten in the sense that the people or social groups who kept them have left the scene. The technology set has shrunk. As a result less than an ideal technology, often a more capital intensive one, may be used.

We would like to stress that in this paper we are not claiming that these things have actually happened in real fisheries. Our aim is the more modest one of explaining how they might happen. Admittedly, however, our experience from fisheries in the developing world have suggested to us that cases like this have occurred.

While our example uses biomass level as the triggering factor for the technological switch, a sudden and dramatic change in factor prices as currently observed in the case of energy cost may conceivably have a similar outcome. The generation of fishers who knew perfectly well to operate sails during varied and changing wind and sea conditions may no longer exist and so the switch back to this now perhaps more efficient technology is not readily possible.

The paper proceeds as follows. It first presents the basic theory which then is followed by a numerical illustration and the presentation of an empirical example that fits closely though by no means completely the theoretical construct. A brief discussion concludes the paper.

THEORY

Consider two technologies referred to as technology 1 and 2. These technologies are partially embodied in fishing capital (boats and gear) as well as human capital (knowledge, training etc.) and social capital (customs, conventions social structures). For concreteness, let technology 1 be more productive than technology 2 in the sense that harvest per fishing unit, a vessel, say, is higher. Thus, technology 1 may be seen as the large scale (industrial) technology and technology 2 as the small scale (artisanal) technology. This characterization, of course, doesn't say anything about the relative profitability of the two technologies.

At any given point of time, each operator in the fishery has adopted one of these technologies. This technology is among other things embodied in his fishing vessel and its crew. Let the corresponding profit functions for each vessel be written as

$$\Pi(e(1),x;1),$$
$$\Pi(e(2),x;2),$$

where the symbol e refers to fishing effort and x to biomass. Note that biomass is the same in both functions but fishing effort may differ.

Profit maximizing behaviour implies that at each point of time, fishing effort is adjusted so as to maximize profits. Two cases are possible. First an upper bound on effort is hit—the vessel is fully utilized. In that case fishing effort is simply a constant. In the second case, profit maximization implies an effort level which may be written as the function $E(x;i)$, i=1,2.

Irrespective of which case applies, profit maximization implies that two profit functions can be written as functions of biomass only:

$$\Pi(x;i),\ i=1,2. \tag{1}$$

And the same applies to the individual harvesting functions:

$$Q(x;i),\ i=1,2. \tag{2}$$

All four functions will normally be increasing in biomass.

Let the number of large scale and small scale fishing vessels by denoted by $n(1)$ and $n(2)$, respectively. The aggregate harvesting and profit functions of the two industry segments will then be:

$$n(1)\cdot Q(x;1) \text{ and } n(1)\cdot \Pi(x,1),$$

$$n(2)\cdot Q(x;2) \text{ and } n(2)\cdot \Pi(x,2).$$

Under open access conditions, the number of fishing units and biomass may be taken to evolve according to the following differential equations:

$$\dot{n}(1) = \phi_1 \cdot \Pi(x;1), \tag{3}$$

$$\dot{n}(2) = \phi_2 \cdot \Pi(x;2), \tag{4}$$

$$\dot{x} = G(x) - n(1)\cdot Q(x;1) - n(2)\cdot Q(x;2), \tag{5}$$

where $G(x)$ is the natural biomass growth function.

To fully examine the model described by (1) to (5) is fundamentally an exercise in natural resource-based industry dynamics. As this is somewhat involved, it may be useful to begin with a study of the situation in biomass equilibrium ($\dot{x} = 0$), i.e. a biologically sustainable state.

It is convenient to consider the biomass equilibrium conditions for the two fleets separately, i.e. as if the other fleet was not operating. In that case, equation (5) shows that the number of fishing units is given by:

$$n(i)\cdot Q(x;i) = G(x), \; i=1,2.$$

Therefore, aggregate equilibrium or sustainable profits are defined by:

$$V(x;1) = \left(\frac{G(x)}{Q(x;1)}\right)\cdot \Pi(x;1), \tag{6}$$

$$V(x;2) = \left(\frac{G(x)}{Q(x;2)}\right)\cdot \Pi(x;2). \tag{7}$$

These two equilibrium profit functions are in many respects the focal point of this paper. They inform us of the maximum profits obtainable by employing each technology for any given level of sustainable biomass. Thus, the function values are measures of economic efficiency in utilizing the fish stock on a sustainable basis and their ratios provide a relative efficiency index.

Under quite unrestrictive assumptions, the aggregate sustainable profit functions are continuous, concave and increasing in biomass until they reach the profit maximizing biomass level. These two sustainable profit maximizing levels would generally not be identical — one of the technologies would normally be able to generate higher sustainable profits than the other. Also, for each technology, there would usually be a positive minimum biomass level below which it would not be possible to make a profit. These cut-off points would generally be different for the two technologies. It follows immediately that there may be technological configurations such that one of the technologies is more efficient at lower levels of biomass and less efficient at higher levels. In other words, there may be a switch in technological efficiency and, therefore, the technology used occurring at a certain level of biomass. An example of this is illustrated in Figure 1 below. It should be noted that the case illustrated in Figure 1 is really just an example of technological switches which is an old subject in production economics (Samuelson 1951, Sraffa 1960, Burmeister 1980). More than one switch, or re-switching, of technologies is also possible (Bruno et al. 1966, Burmeister 1980).

In the case illustrated in Figure 1, the small scale technology (technology 2) is more efficient at relatively high biomass levels. This may for instance be because at relatively high biomass levels dense fish concentrations are found close to the shore so short fishing trips, small boats and simple fishing and fish finding technology can generate good catches. At relatively low biomass levels, however, the large scale technology is more efficient. This can be because now the fish are found further from the shore and therefore longer fishing trips requiring larger boats and more advanced fish finding equipment and more powerful fishing technologies are needed. It follows, as illustrated in Figure 1, that there is a cross-over biomass point, above which the small scale technology is more efficient and below which the large scale technology is more efficient. As Figure 1 is drawn, at a socially optimal biomass point (to the right of the maximum sustainable yield), the small scale technology is preferable.

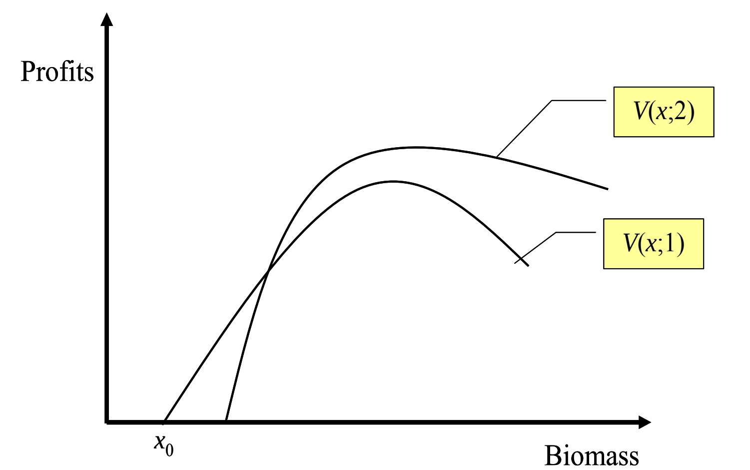

Fig. 1. Equilibrium profit curves for the two technologies

Obviously, under open access conditions, or more generally unchecked dynamics of the common property fishery, the fishery will converge to the large scale technology competitive equilibrium at x0. At this point, only the large scale fishing technology will be used. Indeed long before this point is reached, the small scale boats will have been driven out of the fishery. It should be pointed out, however, that if firms in either technology group are not equally efficient both technologies will be used over considerably wider range than that suggested by Figure 1.

Now, assume technology 2, the small scale technology, is somehow embedded in perishable physical capital as well as human and social capital which deteriorates, in the sense of becoming 'forgotten' if left unused for too long. This occurs because the physical capital perishes or is gradually scrapped if left unused and the knowledge of how to use and maintain it and the associated social structures gradually whither away over time.

We can model this possibility in a simple manner by making the profit function of technology 2 time dependent as follows:

$$\Pi(x;2,t) = \Pi(x;2,0) \cdot D(t)\,, \tag{8}$$

where the function D(t)≤1 measures the decline in the equilibrium profit function of technology 2 during periods of non-use.

So, according to (8), technology 2 is non-constant. It deteriorates during periods of non-use. The available technologies depend on preceding history. They are path dependent. In terms of the diagram, profitability of technology 2 may shift downward over a period of time as illustrated in Figure 2.

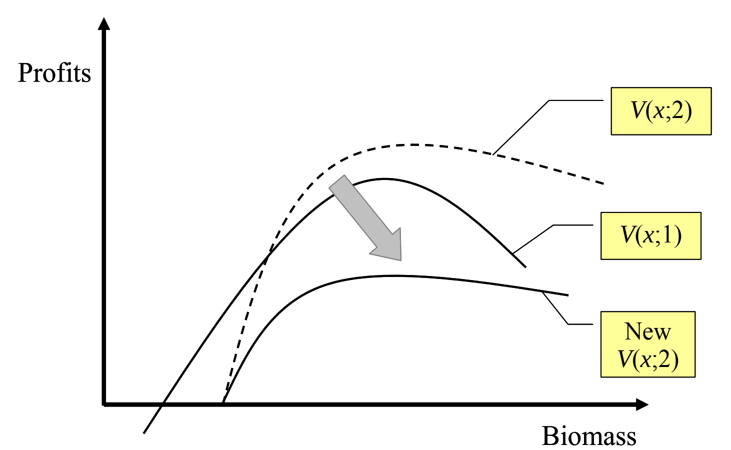

Fig. 2. Equilibrium profit curves: Path dependency

Historically speaking, the fishery may have been operating at a high biomass level using small scale technology (technology 2). Then as the fishery expands biomass falls the large scale technology becomes increasingly attractive until, at some low biomass level, use of the small scale technology virtually disappears. At this point, the advantages of the small scale technology start to deteriorate through the process of 'forgetting' and the profit curve gradually shifts inward as illustrated in Figure 2. If this process continues long enough, then even if biomass recovered through improved fisheries management, the small scale technology would remain inefficient as illustrated in Figure 2. As Figure 2 is drawn, it hasn't quite disappeared from the book of technological blueprints, but it has become sufficiently mouldy for it not to be used again.

Note that the situation depicted in Figure 2 represents a social loss. Not only is there a loss because of the fisheries mismanagement leading to reduced biomass and a switch to the large scale technology (which under the circumstances is economically efficient). There is an additional long term loss because the small scale technology, or at least its advantages, has been lost. This technological loss, may be seen as a loss of a potentially valuable option similar to the loss of potential valuable genetic diversity.

The above arguments establish the theoretical possibility of technological path-dependency in fisheries. Note that it depends on two crucial assumptions:

- There is an initial technological switch at some relatively low level of biomass.
- Unused technologies are subject to the process of 'forgetting'.

The empirical validity of these assumptions remains to be established.

STYLIZED ILLUSTRATIONS

In this section, we provide a numerical example of our theory. The purpose of this exercise is to establish, on the basis of a reasonable fisheries model, the possibility of technological switches of the type discussed above and on that basis trace out some of the implications.

We consider a standard fisheries model with two structurally identical but quantitatively different technologies.

The harvesting functions for each unit are given by:

$$Q(x,e(i);i) = \varepsilon(i)\cdot e(i)\cdot x^{\delta(i)}\text{, } i\text{=1,2.}$$

The variables x and e denote biomass and fishing effort, respectively. The coefficient ε represents catchability and the coefficient δ the degree of schooling behaviour. The index i represents the two technologies.

In accordance with empirical reality, upper limits on fishing effort are imposed

$$e(i) \le \bar{e}(i)\text{, } i\text{=1,2.}$$

This upper limit is arbitrarily set at unity in what follows.

The profit functions are:

$$\Pi(x,e(i);i) = p\cdot Q(x,e(i);i) - c(i)\cdot Q(x,e(i);i) - d(i)\cdot e(i) - fk(i)\text{, } i\text{=1,2.}$$

So fishing costs depend on harvests (e.g. crew share, landings costs etc.), fishing effort (e.g. fuel costs etc.) and a fixed cost component, $fk(i)$. It is worth noting that since the profit function is linear in fishing effort, each fishing unit, provided it is active at all, will always prefer to operate at the upper limit on effort.

The biomass growth function is:

$$\dot{x} = a\cdot x - b\cdot x^2 - n(1)\cdot Q(x,e1);1) - n(2)\cdot Q(x,e(2);2)\text{,}$$

where $n(1)$ is the number of units in the high technology fleet and $n(2)$ the number of units in the low technology fleet.

Since the functional forms for the two technologies are identical, the difference between them is contained in the parameters of the harvesting and cost functions. Below in Table 1 we provide a summary of the values of these and the other coefficients of the model. The technical coefficients are selected with two objectives in mind. First, to be quantitatively reasonable for a large and small scale fisheries technologies. Second, to clearly illustrate the central aspects of the theory developed above.

Table 1
Values of coefficients

	Technology 1 (large scale)	Technology 2 (small scale)
p	1.2	1.2
a	1.0	1.0
b	0.01	0.01
ε	0.1	0.0022
δ	0.9	1.0
$\overline{e}$	1.0	1.0
c	0.5	0.4
d	0.5	0.025
fk	0.01	0.001

The biomass growth coefficients in Table 1 imply possible biomass levels over the interval [0,100], with a maximum sustainable yield of 25 biomass units happening at biomass equal to 50 units.

According to the numerical specifications in Table 1, the catchability coefficient for the large scale technology is about 45 times that of the small scale technology indicating that each unit is capable of catching much more per unit effort given the same effective biomass. The maximum effort level is the same (i.e. unity). However, the schooling parameter for the large scale technology is slightly smaller than for the small scale technology implying that the former are less dependent on the stock size possibly because of a greater geographical range and better fish finding technology. In combination, these specifications for the harvesting function suggest that for a reasonable range of biomass levels each large scale unit can catch about 35 times that of a small scale unit.

For the cost function, the specifications in Table 1 imply that the marginal cost of catch is about 20% higher for the large scale technology than the small scale one. The main rationale for this is that preservation, storage and landing costs of catch are higher for large scale vessels than small scale ones. This is primarily due to longer trips and higher catch volume. Marginal effort cost, d, is 20 times higher for the large scale technology. This of course is because effort units for the large scale vessels are much bigger than for the small scale vessels. Note that this difference does not nearly compensate for higher catch per unit effort. Finally, fixed costs for the large scale technology are taken to be 10 times higher than the small scale technology. This is intended to reflect much higher capital costs for the former.

On the basis of the above specifications, we can now illustrate the aggregate equilibrium profit functions for the two technologies as in Figure 3.

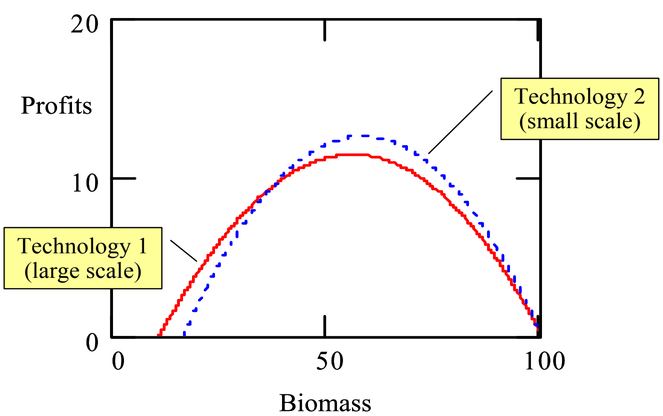

Fig. 3. Numerical model: Equilibrium profit functions

As indicated in Figure

3, the maximum equilibrium profits for the small scale technology are higher than those of the large scale technology for most of the relevant biomass range. However at small levels of biomass, the large scale technology becomes more efficient in this sense. The cross-over or switching point occurs at biomass equal to 37.5 units or roughly one-third of the virgin stock biomass. The maximum sustainable profits for the small scale technology, moreover, are substantially higher than for the large scale technology and it occurs at a higher biomass level. It is interesting to note, however, that as biomass approaches the virgin stock, the difference in efficiency between the two technologies becomes very small again. This, of course is because at these biomass levels sustainable harvests are very small.

Finally note that the competitive equilibrium, i.e. the biomass at which there is no profits, is considerably lower for the large scale technology than the small scale one. This, of course, reflects the fact that the former is more efficient at low biomass levels.

Further statistics of relevance are listed in Table 2.

Table 2
Key comparative statistics

Competitive equilibrium	Technology 1 (large scale)	Technology 2 (small scale)	Percentage difference
Biomass	10.8	16.4	51.8%
Number of units	11	380	
Aggregate harvest	9.6	13.7	42,7%
Aggregate profits	0	0	
Optimal equilibrium			
Biomass	55.9	58.2	4.1%
Number of units	7	190	
Aggregate harvest	24.7	24.3	-1.7%
Aggregate profits	11.4	12.6	10.5%

While neither sector would make any profits in competitive equilibrium, they are not identical from a social perspective. The small scale competitive equilibrium appears unequivocally superior to than the large scale one. The main reason is that it corresponds to a larger biomass. Therefore, with improved fisheries management, which requires a re-building of the biomass, the resulting present value of profits would be higher starting from the small scale competitive equilibrium than the large scale one. Also, at the small scale competitive equilibrium, sustainable harvests are higher than in the large scale competitive equilibrium.

The main difference between the optimal equilibria for the two technologies is that sustainable profits are substantially higher for the small scale technology. This, of course, is a consequence of the specification of the model coefficients and does not hold in general, even when there is a technological switch. The technology more efficient at low biomass levels may also have the higher maximum sustainable profits as can be easily verified by the appropriate redrawing of the curves in Figure 3. The same graphical exercise also indicates the possibility of re-switching, i.e. that the same technology being more efficient at lower and higher biomass levels. This, however, may not be possible for the fisheries model specified in this exercise.

Now, let us assume that the fishery has evolved to a point close to the large scale competitive equilibrium point so that technology 2 is left unused. Then, as discussed in section 1, this technological ability begins to deteriorate according to the function D(t). An interesting question is when has the process of deterioration gone so far as to make technology 2 unavailable, even if biomass recovers. Obviously, this depends on the initial efficiency of technology 2 relative to technology 1 and the process of deterioration. The first factor is defined above so we only need to specify the latter.

It seems reasonable that the speed of deterioration is very slow at first and then increases with the passage of time. In that spirit let the deterioration function be defined by:

$$D(t) = 1 - 10^{-2} \cdot t - 10^{-5} \cdot t^2 .$$

According to this specification, the technology has deteriorated by 0.5% after 5 years of idleness, 1.1% after 10 years and 2.8% after 20 years. After 50 years or roughly 2 generations it has declined by 17.5%. After that the speed of deterioration picks up substantially and the technology has been completely lost after about 95 years. The complete graph of the deterioration function is illustrated in Figure 4.

According to the above process of technological deterioration, technology 2 ceases to be more efficient than technology 1 at any biomass after a period of about 43 years of non-use. From that time onwards there is no switching point. This means that even if biomass would increase, the use of technology 2 would not re-emerge and its decline would continue until it was completely forgotten. The resulting social loss is indicated in Table 1.

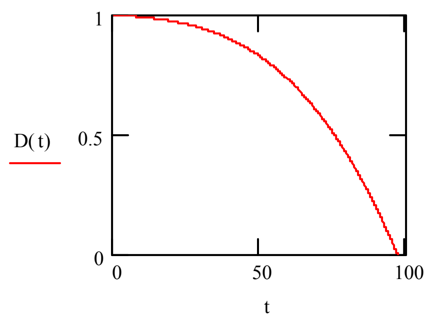

Fig. 4. A Deterioration Function

Obviously different specification of the deterioration function would lead to different dates of non-reversibility. That, however, is not the point. The point was much more limited, just to establish the empirical possibility of technological path dependency discussed in section 1.

The dynamics of the situation are even more illuminating. Let us for the sake of illustration specify the fleet adjustment dynamics (equations (3) and (4) above) as $\phi_1 = 0.1$, and $\phi_2 = 4$.

The following diagrams illustrate the evolution of the two fleets and biomass. The starting point is characterized by very few boats and close to virgin stock biomass.

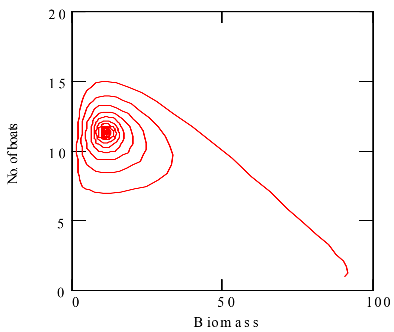

Fig. 5. Only large scale fleet: Evolution of boats and biomass

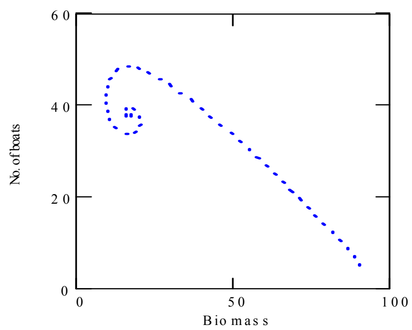

Fig. 6. Only small scale fleet: Evolution of boats and biomass (Number of boats divided by 10)

It is more interesting is to see what happens when both fleets operate jointly. Let us start with a sizeable small scale fleet and the initial entry of the large scale fleet. The evolution of the two fleets operating jointly is illustrated in Figure 7.

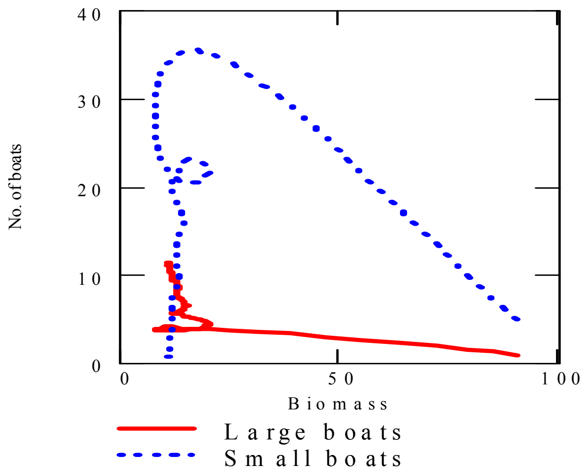

Fig. 7. Both fleets operate jointly: Evolution of boats and biomass
(blue dots=small scale boats (divided by 10) red solid line=large scale boats)

As illustrated in Figure 7, the evolutiton starts at high biomass (horizontal axis) and a relatively few small scale boats and only one large scale boat. Initially profits are good and both fleets expand. At a certain point, however, the biomass has been reduced to a point where the small scale fleet is not profitable and its starts to decline, but does so in a fluctuating way. The large scale fleet, enjoying superior technology at low biomass levels, however, is still profitable and keeps on expanding (albeit in a fluctuating way. These fleet and profitability dynamics over time are illustrated in Figure 8. Ultimately the small scale fleet is totally driven out of the fishery and only the large scale fleet is left to exploit a much reduced stock of fish at bioeconomic equilibrium where there are no profits.

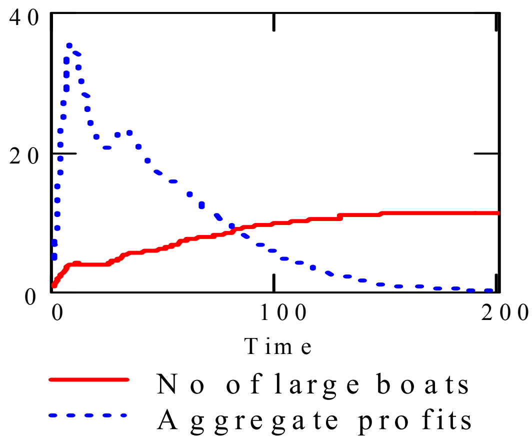

Fig. 8. Number of boats and aggregate profit over time

POSSIBLE EMPIRICAL EXAMPLES

Empirical examples to illustrate and test the above theory are not readily available. The reason is not necessarily that such examples do not exist, but that the appropriate empirical research has not been undertaken. To collect the necessary data and systematically compare it to the theory is a considerable undertaking.

One example of a fishery illustrating to some extent our theory is the small-pelagic beach- or shore-seine fishery in the Indian State of Karnataka. Small-pelagic fish are, in terms of volume, among the largest fish resources along the South West coast of India. Historically the major catch of these species in the State of Karnataka was produced by large shore-seines deployed by traditional rowing craft close to shore and then pulled ashore by numerous fishers. (The essential technology is illustrated in Figure 9. It should be noted that the shore-seines use in Karnataka were actually much larger than the one sketched in Figure 9 and not bag-shaped but much more similar to traditional wide-net seine. These seines were invariably collectively owned and operated.

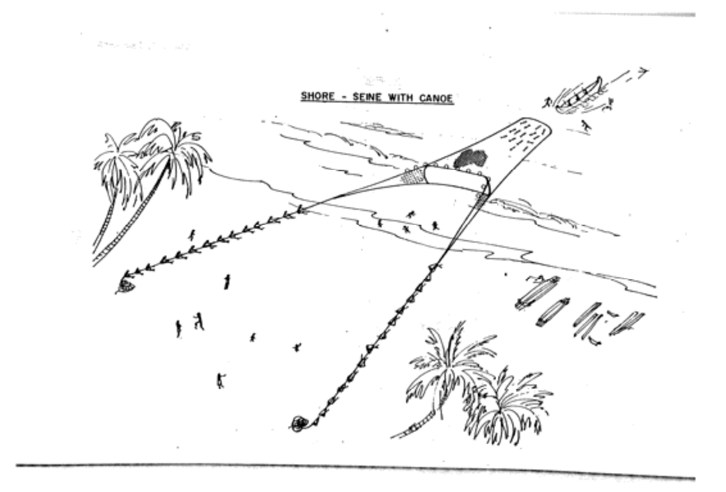

Fig. 9. Shore Seine Technology (Source: Kurien & Willmann 1982)

This fishery entailed waiting for dense schools of fish to come close to shore on their seasonal migrations governed by the annual monsoon periods. High stock sizes usually implied greater availability of schools close to shore while in periods of low abundance, shore-seine catches were low.

In the years around 1980, the Karnataka shore-seine fishery was in a relatively few years replaced by a newly introduced purse-seine fishery which initially operated the nets manually but soon shifted to mechanical net-haulers that displaced labour onboard of the vessels. Given the purse-seiners greater range and ability to intercept the stocks prior to coming close to shore, the traditional shore-seine technology was competitively inferior and doomed to disappear and with it the social institutions that governed its operation. These included the norms governing access to shore-seine localities and the deployment of the nets in near-shore waters as well as the social rules for the sharing of the catch, income and costs across a large number of fishers and associated shore labourers. While for some years, collective ownership continued with some purse-seine vessels, it gradually gave way to individual ownership.

Quite a different development was observed in the adjacent State of Kerala. As a consequence of the configuration of the coast but possibly also because of a greater diversity in marine resources including abundant shrimp stocks, the same small pelagic resources in this Sate were harvested by traditional encircling nets operated from large-sized dugout or plank built boats (Figure 10). As in the case of Karnataka shore-seines, these fishing units were also collectively owned and operated.

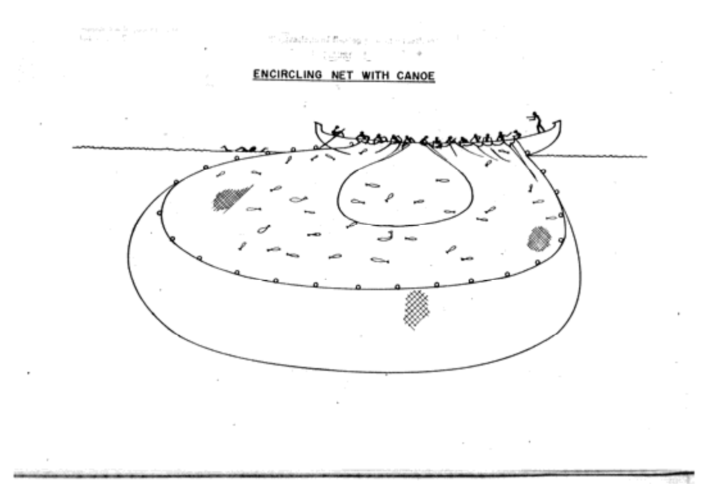

Fig. 10. The Kerala Encircling Net Technology (Kurien & Willmann 1982)

This technology had a greater ability than the shore-seines to adjust to varying stock sizes and adapt motorization in the early 1980s. This dramatically increased its versatility and range thereby successfully emulating a modern technology without a switch to purse-seining. This development was helped by the State government at that time through the banning of the introduction of purse-seining in its waters. It also allowed for continued technological adaptibility and inovation such as the shift to ring-seine nets and the adoption of new boat-building materials and techniques. The collective social capital could be succesfully maintained conferring greater resilience to economic crises including, for example, rotational manning of vessels to achieve greater income-spread as well as access to investment capital.

The above diverse developments in Karnataka and Kerala suggest that there is one aspect of "real fisheries" which has not been taken into account in the conventional fisheries models. This is the incentive for technological adaptation that arises as biomass level decline (or else factor prices change, perhaps suddenly). Motorization in small-scale fisheries has greatly extended the range of fishing craft. This adaptation has allowed small-scale fishers to adjust to declining inshore stock abundance. However, the extent of adaptability hinges on access to capital and know-how which is not equally available to all small-scale fishers resulting in stratification and disadvantaging the poor and possibly also old fishers whose ability to learn new techniques is less. As shown above, the maintenance of social capital conferred a greater resilience to change.

DISCUSSION

This paper has the simple objective to refute the usual hypothesis that the economically more efficient technology always outcompetes the less efficient one. This hypothesis has usually been taken to hold for the exploitation of common pool renewable natural resources such as fish stocks. We have shown that when the efficiency of a technology depends on the size of the biomass, the efficient technology may switch as the stocks become increasingly exploited. Combined with a possible loss of social capital, this technological switch may become irreversible and a return to the more efficient technology impossible as stocks recover.

There is another type of inefficient technology use in a common pool resource use. In the exploitation of mineral oil reserves, it is well known that the rate at which oil is extracted can strongly impact the aggregate yield and profits from an oil field. The faster the exploitation rate, the lower is the aggregate yield, the higher marginal extraction costs and lower overall profits from the resources. In a common pool situation, e.g. an oil field exploited competitively by several users, the technologies adopted would arguably be the fast and "inefficient" ones.

A similar reasoning could be applied to the exploitation of a renewable fish stock. The competitive fishing down of a fish stock toward (optimal or suboptimal) bioeconomic equilibrium may be seen as a race between two competing technologies. A capital intensive technology would entail a high harvest rate over a short period of time before the zero-profit equilibrium is reached. A labour intensive technology would entail a comparatively low harvest rate but take a longer time to reach the zero-profit equilibrium. The overall profits from the labour intensive technology path could easily be higher than for the high technology path. In that sense the capital intensive technology is less efficient. However, competitive forces would call for the use of the capital intensive technology. Thus, it appears that the competitive race, while ultimately leading to the "survival of the (available) best", can allow an inferior technology to dominate the exploitation of a common pool resource until most of its resource rent has become dissipated.

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REFERENCES

Arnason, R., G. Magnusson and S. Agnarsson. 2000. Herring Fishery Games. *Marine Resource Economics* vol 15:293-319.

Arrow, K.J. and F.H. Hahn. 1971. *General Competitive Analysis*. Holden-Day. San Franscisco.

Bruno, M. E. Burmeister and E. Sheshinski. 1966. *The Nature and Implications of Reswitching Techniques*. The Quarterly Journal of Economics 80.

Burmeister, E. 1980. *Capital Theory and Dynamics*. Cambridge Survey of Economic Literature. Cambridge University Press.

Debreu, G. 1959. *Theory of Value*. Cowles Foundation. Monograph 17. Yale University Press, New Haven.

Koopmans, T.C. 1951. *Activity Analysis of Production and Allocation*. Wiley NY.

Malinvaud, E. 1972. *Lectures on Economic Theory*. North Holland. Amsterdam.

Kurien, J. and R. Willmann. 1982. Economics of artisanal and mechanized fisheries in Kerala. A study on costs and earnings of fishing units. Working Paper No. 34. FAO/UNDP Project Small-Scale Fisheries Promotion in South Asia. Madras, India. 112p.

Romer, D. 1996. *Advanced Macroeconomics*. McGrqaw-Hill Companies New York.

Samuelson, P.A. 1951. *Abstract of a Theorem concerning Substitutability in Open Leontief Models*. In T.C. Koopmans (editor). Activity Analysis of Production and Allocation.. Wiley NY.

Solow; R.N. 1956. *A Contribution to the Theory of Economic Growth*. Quarterly Journal of Economics 70:65-94.

Sraffa, P. 1960. *Production of Commodities by Means of Commodities*. Cambridge Univeristy Press. Cambridge, UK.